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IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Application of:	
Con-Carolis et al.	Group Art Unit: 2613
For: PHOTONIC COMMUNICATION SYSTEM WITH "SUB-LINE RATE" BANDWIDTH GRANULARITY PROTOCOL TRANSPARENCY AND DETERMISTIC MESH CONNECTIVITY	Examiner: Quan Zhen Wang
Serial No.: 10/655,209	
Filing Date: September 4, 2003	

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Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Dear Sir:

Enclosed herewith please find a certified copy of Canadian Patent Application No. CA 2339902 and a certified copy of PCT/CA2002/000301 to support Applicants' claim to priority in the subject patent application.

Respectfully submitted,

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Canadian Patent Office

Certification

This is to certify that the documents attached hereto and identified below are true copies of the documents on file in the Patent Office.

Specification and Drawings, as originally filed, with Application for Patent Serial No: **CA 2339902**, on March 7, 2001, by **CEDRIC DON-CAROLIS and PETER MCILROY** for "Photonic Communication System with Sub-"Line Rate" Bandwidth Granularity".

Sylvie Grégoire

Agent certificateur/Certifying Officer

April 11, 2006

Date

Canada

(CIPO 68)
31-03-04

OPIC

Abstract:
A data format and control protocol for a communication system is presented which allows purely photonic connections between network edge components. The format uses time slot based TDM channels to allow all optical switching of the channels between different signal paths in the switch nodes, and time slot by time slot WDM to reduce the probability of blocked connections. The connection protocol uses conventional 'least cost' path calculation algorithms to identify target connection routing through the network, a path integrity process to ensure capacity, and link removal and recalculation in cases of blocked connections. The time slot and wavelength map can be represented as a two dimensional matrix. Availability calculations can be done using simple matrix logic operations. System operation with bands of optical wavelengths is discussed.

Provisional Patent Disclosure:
Inventors: Cedric Don-Carolis, Peter McIlroy

Title:
Photonic Communication System with Sub-"line rate" Bandwidth Granularity

Subject:
This disclosure relates to optical communication systems. It describes an improvement over existing optical communication systems: the provision of full optical management of data bandwidths less than the line rate of the transport on a given optical frequency. The disclosure describes a connection protocol for use with the described signaling format and switching method to enable connection oriented bandwidth management at the sub-lambda level.

Outline:
Photonic communication systems which include switching nodes which route optical signals without converting the signal from optical to electrical signals and back to optical again (OEO conversions) are soon to move from the lab to practical deployment. These systems provide substantial benefits over existing systems, in which optical signals are switched almost exclusively in the electrical domain, but they also have shortcomings. These systems are based on switching all the data in a given wavelength from one path to another, resulting in either inefficient transport, due to low data rates, or excessively large bandwidths being switched. A key impediment to more efficient processing of the bandwidth is the data transmission format, typically SONET, which does not lend itself to simple optical management. An alternative method being pursued is the use of optical packet switching, in which, analogously with electrical packet switching, optical packets with associated routing information are transmitted and optical switches must determine the appropriate route for each packet. These systems must deal with contention for transmission resources at each node, require substantial effective bandwidth for each packet label, require extremely high speed optical switches, and require high speed processing at the nodes to determine the appropriate path through the node. An improvement is presented in this disclosure: the optical signal is presented to the network with a format conducive to optical management as a connection with a rate less than or equal to the line rate, but in a format which does not require very high speed operations, and photonic switches are employed which enable the bandwidth management. The optical path for data through the network is established once per connection, and so all contention issues can be resolved in longer times or the connection can be disallowed, without the danger of a partial connection. The removal of both the OEO operations and the need for large bandwidth aggregation machines (Terabit MPLS, ATM or STS cross connects) results in substantial savings in the capital and operating costs of a photonic network.

Figure 1 describes the usage of various terms by way of a flow schematic. The communication system described relies on time domain multiplexed (TDM) and wavelength domain multiplexed (WDM) data units and optical switch nodes to provide the managed optical transport. (Figure 2) Each transmitter can provide a single colour at any given time, so the timeslot matrix is 'singly filled'. The optical switch nodes are able to route the optical data units (ODUs) through the nodes, and so overlay the link state matrices (fig. 3) to make multiply filled matrices, with each ODU entering the switch from a fibre following the required path through the node and onto the appropriate output fibre . The ODUs exist as fixed length frames in time slots within a repeat interval. For example, sixty four 40 microsecond frames will fit within a 2.56 ms

repeat interval. If the nominal line rate is ~10 Gb/s, then each frame within the repeat interval equates to a connection of ~150 Mb/s. An managed granularity map (fig.4) for the example of an 80 wavelength system is shown for 1 slot, 16 slots and 64 slots per wavelength, demonstrating the improvement. A connection from a transmitter to a receiver is formed as an optical signal, which is transmitted in the correct timeslot and at the desired wavelength on the ingress optical fibre, and the path through the network, which is controlled by the optical switches through which it propagates (fig. 5). The choice of wavelength and timeslot for transmission is determined by the network connection setup system and connection setup protocol. Figure 6 shows how the system could be run in parallel with other systems in an optical network.

Fig. 7 list some attributes of the invention.

The precise timing of transmitter output is controlled by the system management to ensure the phase of the frames generated by the transmitter is aligned to the optical switch node timing when the frames arrive at the optical switch. Frames arriving from other switch nodes are phased appropriately by propagation through switched fibre delay line systems which align the frames to the switch operation.

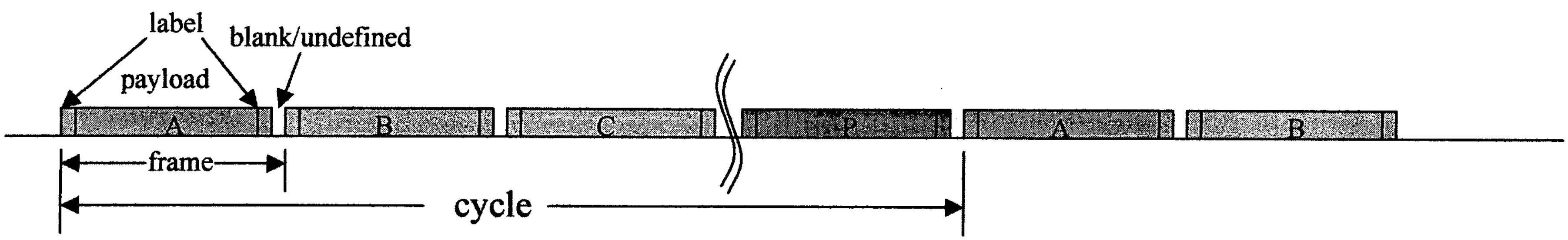
The protocol which controls the setup of a 'connection' is shown in figs. 7 to 15.

We claim:

1) An optical communication system, in which:
   a) sub line-rate optical data streams are transmitted as frames of fixed duration, fixed repetition interval, fixed frame phase within the repetition interval, and fixed wavelength, each frame containing line-rate bursts and some overhead signaling; The data rate associated with one frame of data and its corresponding repeat interval being the base data rate, the total data rate of the frames within a repeat interval being the line-rate minus the bandwidth required for overhead signaling. The wavelength, local phase and fibre being the communication state for the data.
   b) each frame is transmitted to have a unique combination of wavelength and phase on any traversed fibre path from source to destination.
   c) photonic switch nodes are used to connect optical data presented at the input ports to appropriate output ports, each frame in a line-rate flow being routed individually.
   d) fully photonic connections between the source and destination are achieved through routing the frames from the transmitter to the receiver, ensuring there are never two frames of the same wavelength and local phase impressed on the same optical fibre.
   e) data rates higher than the base data rate are achieved through re-packaging the data into multiple base data rates.
   f) optical to electrical to optical conversion is performed as required to ensure signal fidelity.
   g) optical wavelength conversion may be performed as desired, providing the resulting frame will not exist in the same phase and fibre as another frame of the same wavelength
   h) a communication means exists for communicating between network elements.
   i) time delay means are used to align incoming frames of different wavelengths and on different fibres to allow synchronous optical switch operation.

Terminology

Tx/Rx Data description



- The frame (an optical data unit) is the fundamental unit of bandwidth
  - larger BW achieved through the use of multiple frames
- Each frame in a cycle may have a different wavelength
- The same frame in each cycle has the same wavelength
- Frames are routed as connections
- Optical switches overlay cycles
  - the management system ensures there are no data collisions
- Optical switch transition occurs during the blank/undefined time

figure 1

Wavelength Agile Bandwidth Mapping

Each Tx transmits in sequential timeslots

-can transmit any wavelength in each timeslot

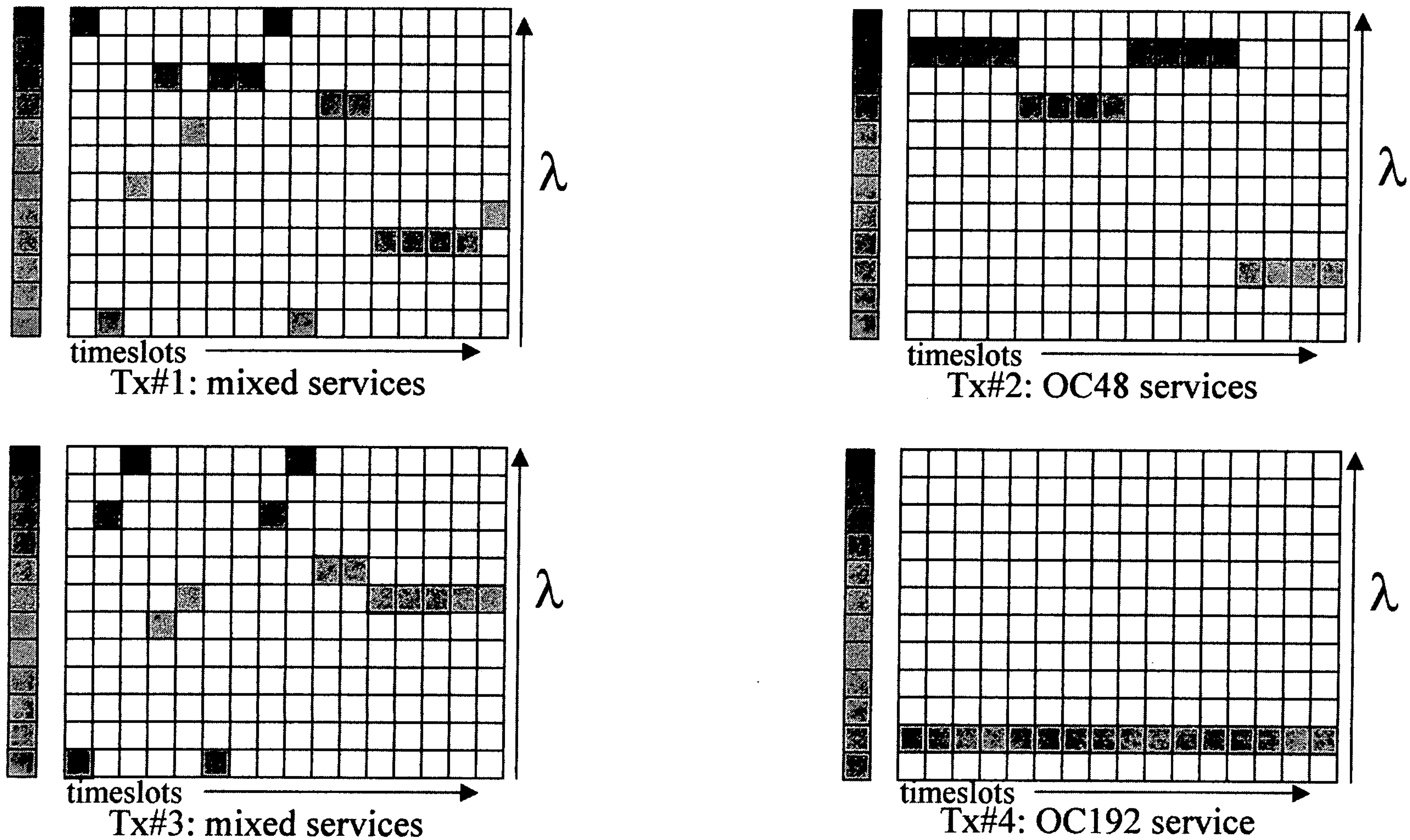
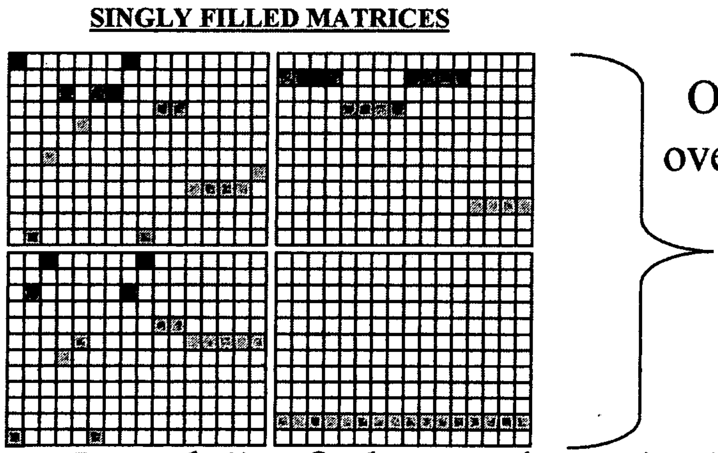
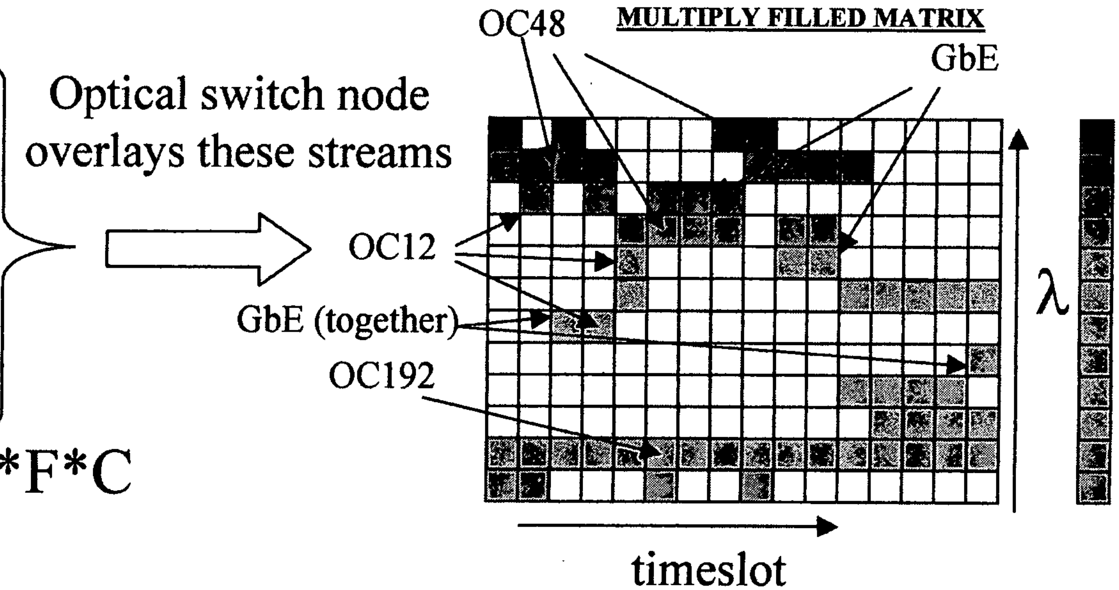


figure 2

Bandwidth Aggregation





- Total # of channels=S*F*C
  - S: # of slots
  - F: # of Fibres
  - C: # of colours (λ's)
- e.g.: S=16 @ OC12, C=40, F=6
  - Total # of OC12 channels=3840

Photonic link state matrix

High bandwidth services need not be contiguous in either timeslot or wavelength

The management system ensures that when signals from multiple transmitters are to be muxed over common fiber, the colours selected per timeslot by each Tx are not overlapping with other Txs

figure 3

CA 02339902 2001-03-07

Granularity maps

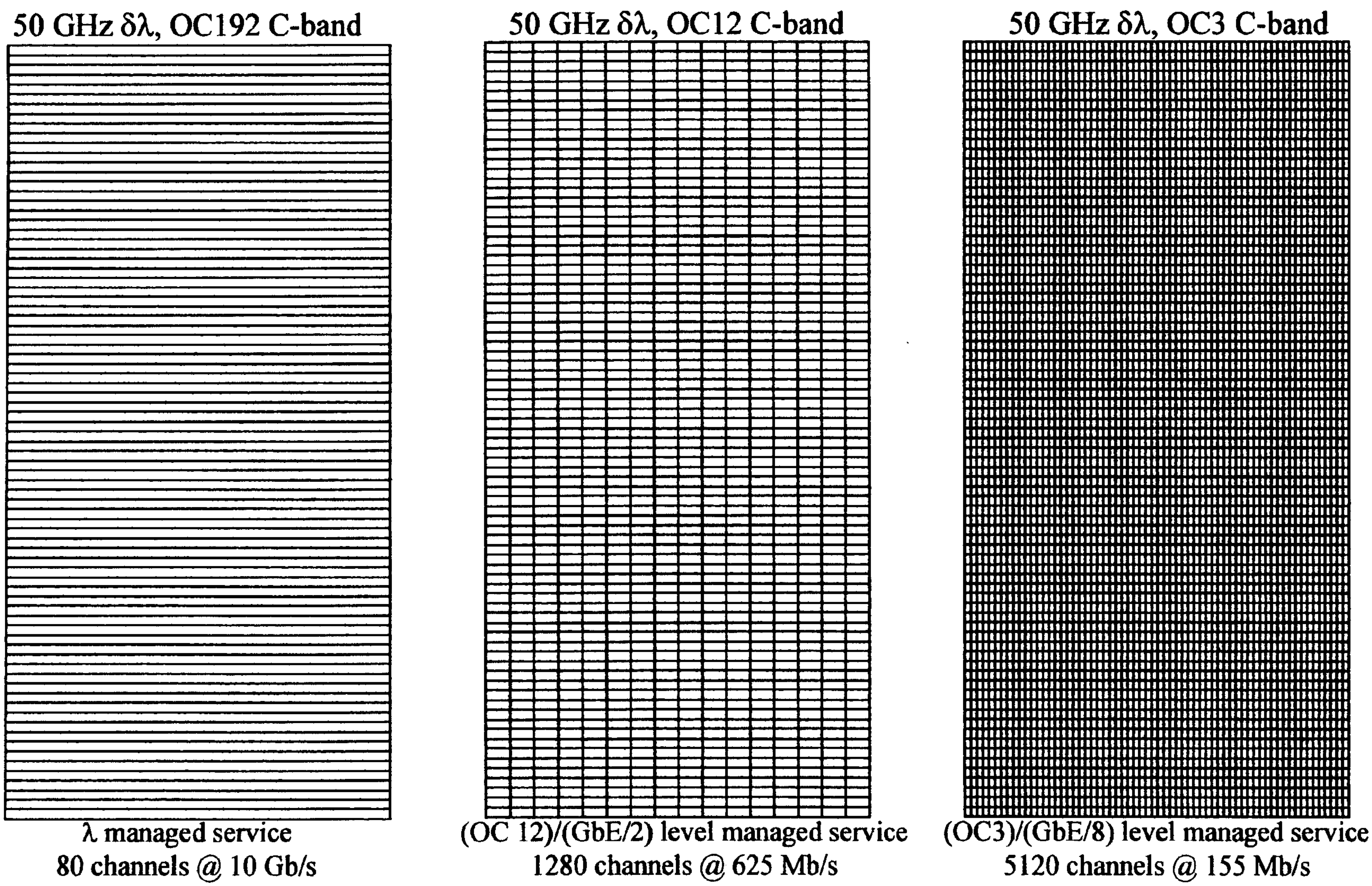


figure 4

Granular Bandwidth Management

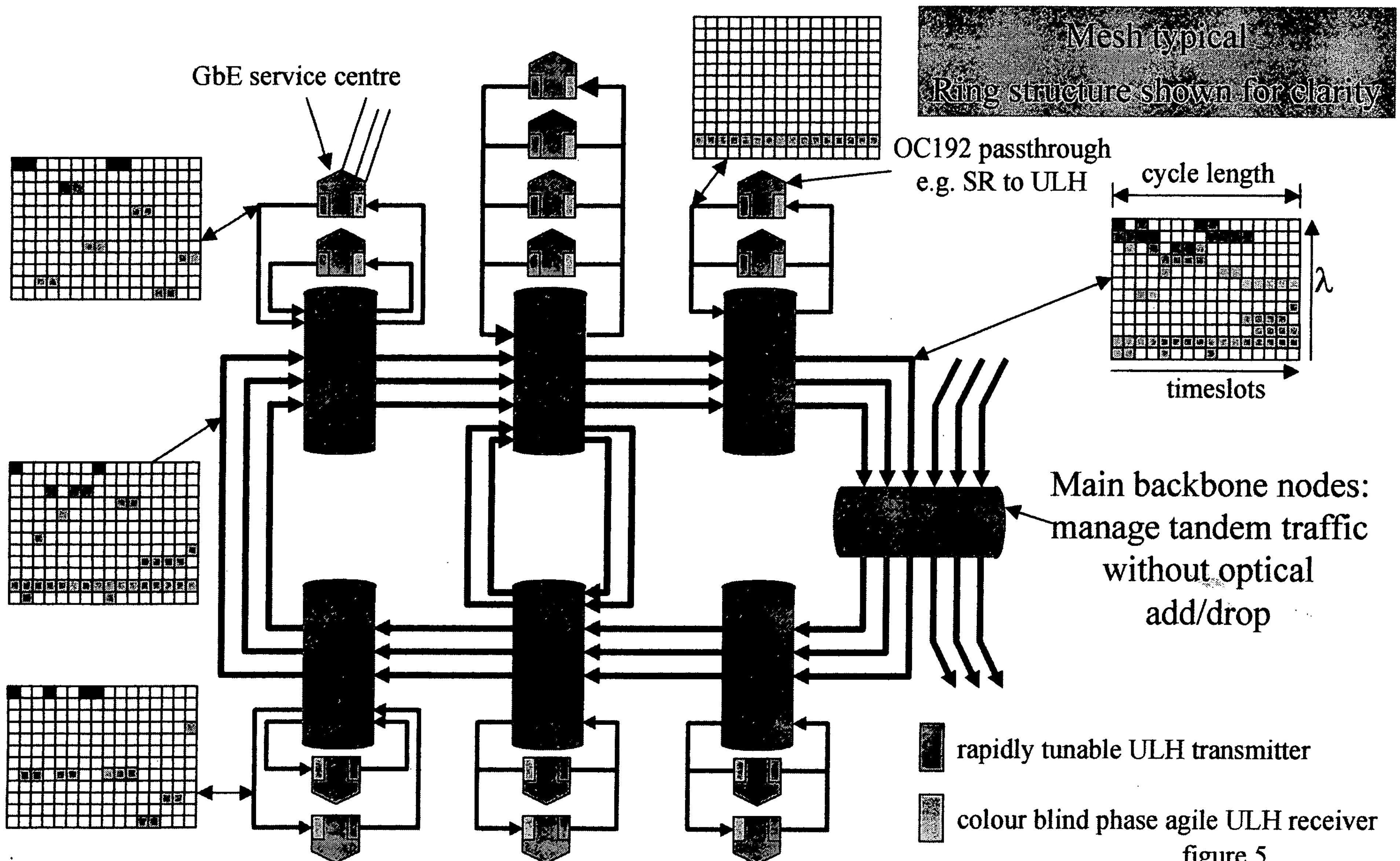
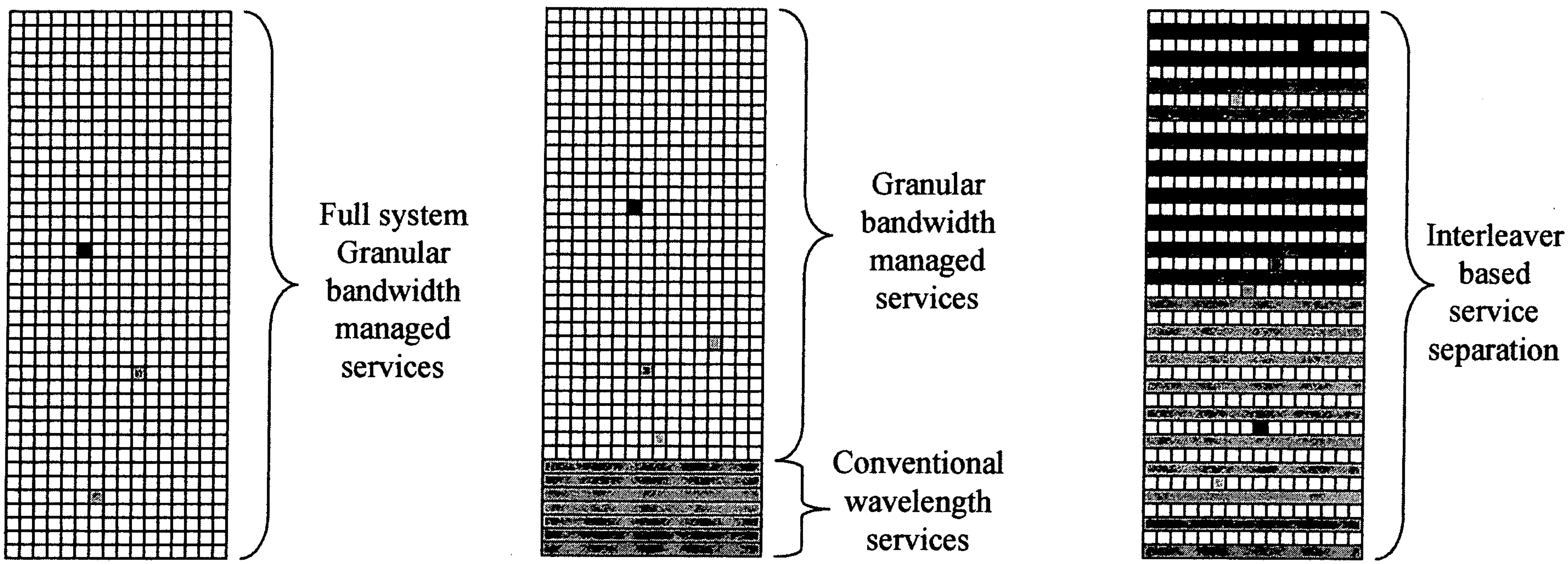


figure 5

Photonic Layer Format Compatibility



Matrices show 40 colour (e.g. C band @ 100 GHz), 16 frame/cycle configuration:

640 OC12 channels

easily extended to 80 colour, 64 frames/cycle:

>5000 OC3 channels

Demonstrates ability to overlay and operate over existing/future λ level routing

figure 6

Operational principle

- Connection oriented
- Data transported as frames in time slots on wavelengths on fibres
  - Repeating cycle: fixed number of fixed length time slots on each wavelength
    - The cycle time is chosen based on update rate and latency
    - The time slot dimension is chosen for optimum BW granularity
      - minimum managed BW is (line rate)/(# of timeslots per cycle)
  - A connection is a timeslot, colour and fibre combination available through the system from source to destination
    - Transmitter provides dynamic wavelength allocation for each timeslot
      - allows access to all operational system wavelengths
- Optical switching is used for fibre to fibre routing of frames through the network
  - Each fibre supports multiple wavelengths
  - Each wavelength supports multiple timeslots

figure 7

CA 02339902 2001-03-07

CA 02339902 2001-03-07

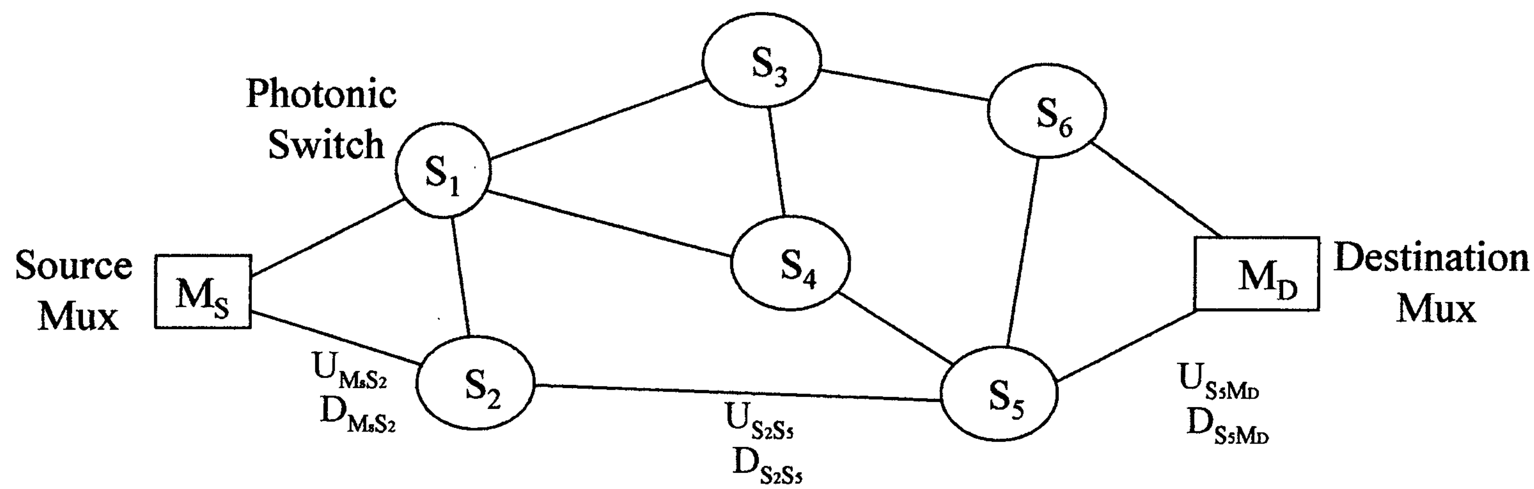
Bandwidth Management

- Three dimensions of bandwidth separation and management
  - space (different fibres)
  - time (different time slots)
  - colour (different wavelengths)
- The optical switch manages bandwidth in the space domain
- The multiplexor electronics manage bandwidth in the time domain
- The tunable transmitter manages bandwidth in the colour domain
- The management system provides call setup and tear down

- Additional functions:
  - regeneration handled by sparse O/E/O at edge muxes as required
    - colour conversion and Time Slot Interchange by muxes if desired
  - path restoration mechanism
    - Diversity through mesh network

figure 8

'Line of Sight' Connection Protocol: Simplified Example

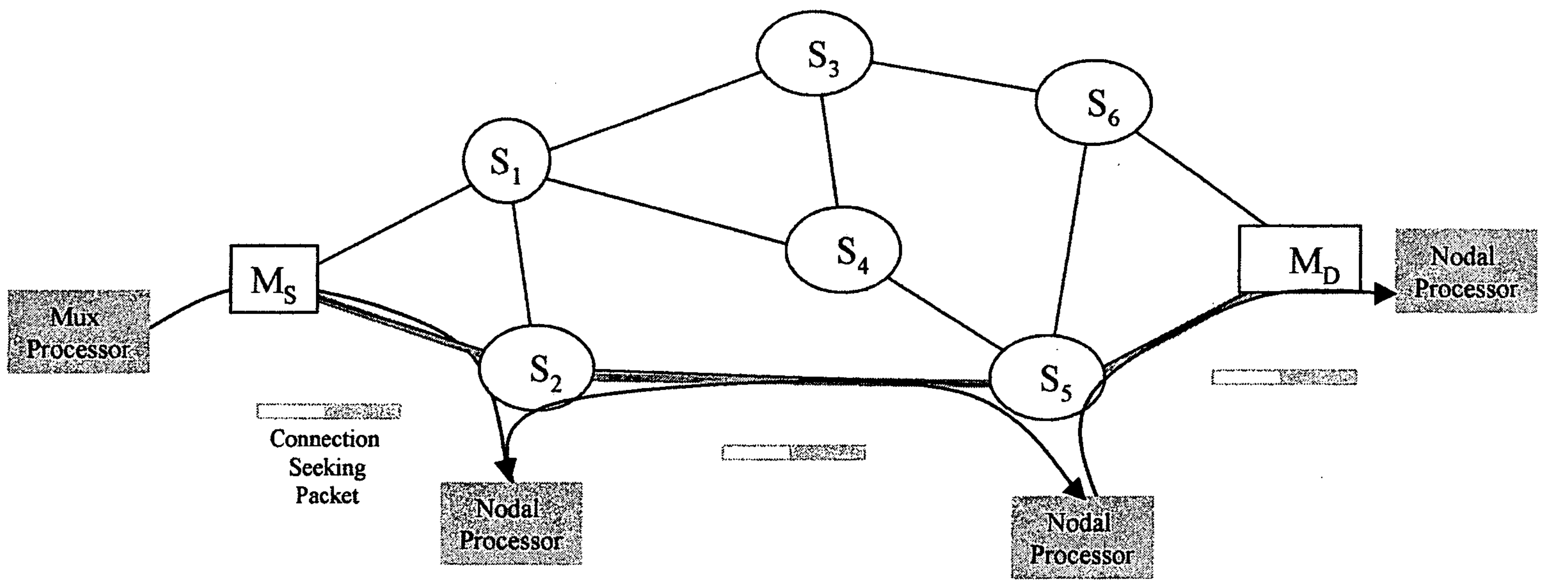


- Each link with two metrics
  - % utilization (example: $U_{M_SS_2}$)
    - (updated every 10 minutes or so from Switches to all muxes)
  - Nominal Distance (example: $D_{M_SS_2}$)
    - Configured at system start-up to reflect link cost (distance)
  - Link State information kept locally at Switches

Try Shortest, Least Congested Route First

figure 9

Connection Request



- End-user requests connection
  - N OC-3s from Source Mux (M_S) to Destination Mux (M_D)
- M_s computes Dijkstra to determine shortest nominal path to M_D
  - Dijkstra link cost parameter is product of %Utilization and Nominal Distance
  - Example: Route selected is (M_S / S_2 / s_5 / M_D)
  - It doesn't know if channels will be free yet
- 'Line of Sight' Protocol finds open channels from source to destination
  - Mux processor at M_s sends Connection Seeking Packet to first switch on selected route
    - Sent via OC-3 IP control network
    - Redundant Routers or ATM Switches at each node
  - Nodal processor at S_2 updates the packet and sends it on to next switch etc. until M_D is reached

figure 10

Connection Seeking Packet (CSP)

- Encapsulated in IP and transmitted from node to node along selected route
  - Updated at each node before retransmission
- Connection Seeking Packet Identifier (56 bytes)
  - M_S , M_D , Selected route, VPNID, Priority, BW, Time of Request, Blocking event register
- Blocking Link (4 bytes)
  - Identifies 'Most Blocking Link' encountered so far
  - Used to eliminate worst link in the event of blocking
- "Line of Sight' State (320 bytes)
  - 2560 bits
    - One for each of 64 timeslots and 40 colours
    - 0's indicate open slot/colour channels
  - Begins at M_S with full set of connection possibilities available at mux
  - Updated at each intermediate switch on the way to M_D
    - Logical OR with next Link State word

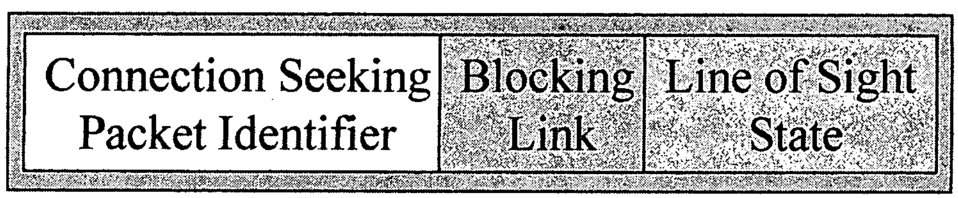
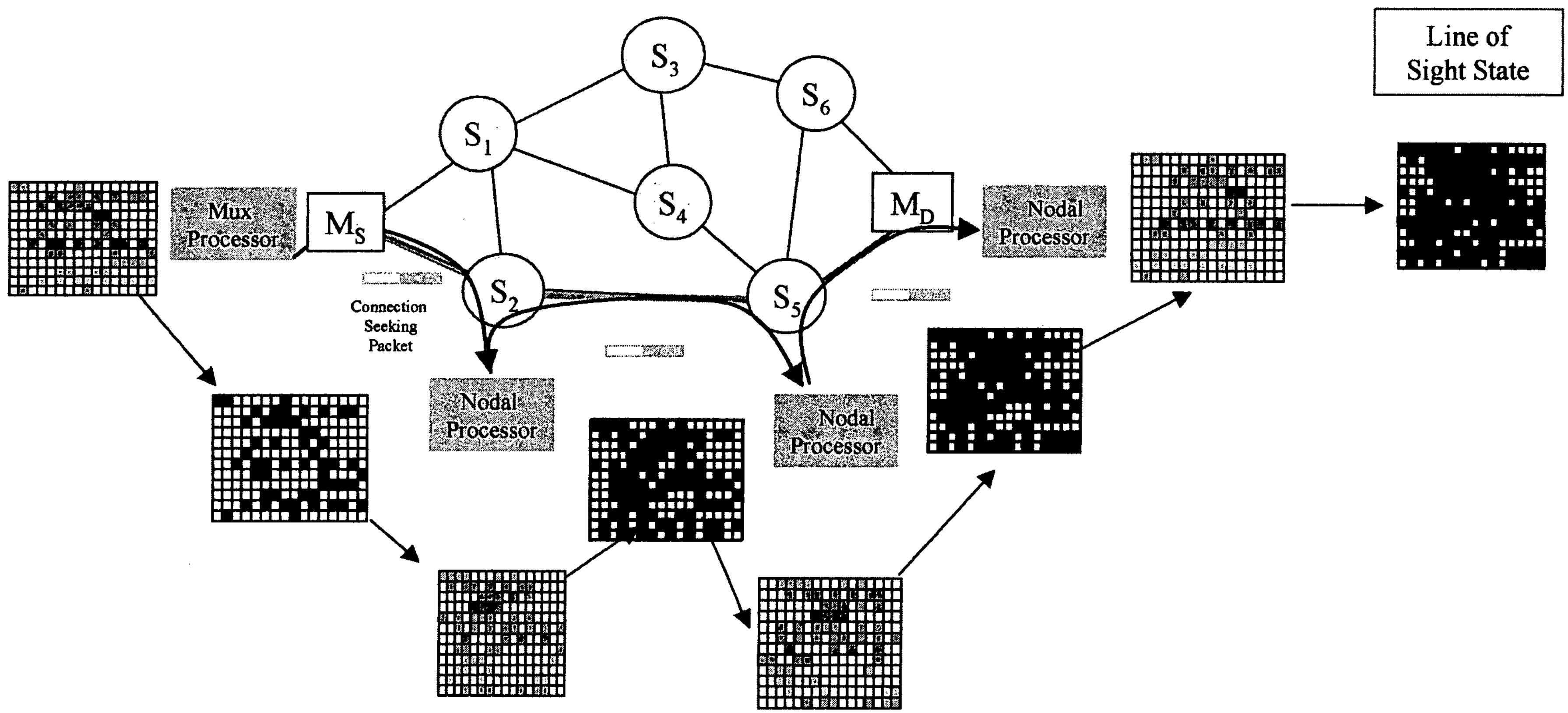


figure 11

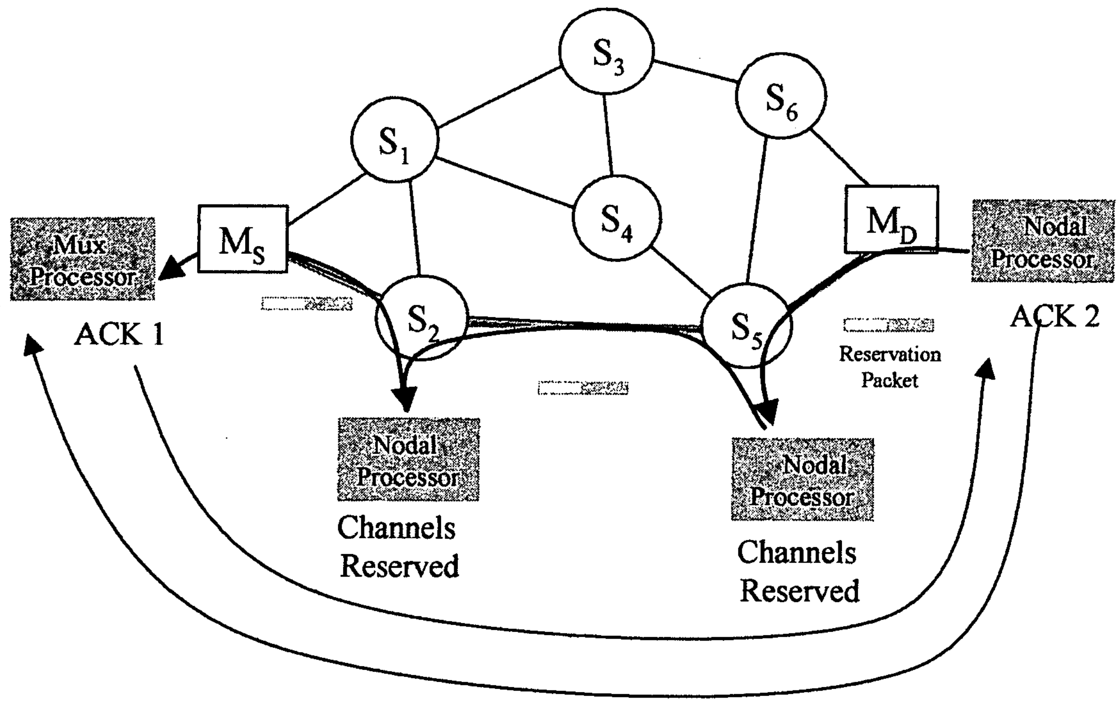
Identify Open Channels on Best Route

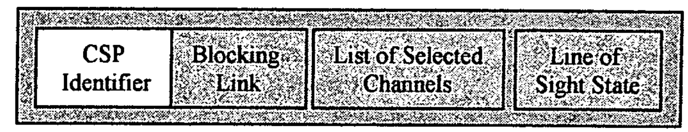


- Line of Sight progressively occluded as CSP traverses Route
- At each step, the number of channels blocked is calculated
  - Blocking Link field is updated if new link worse than other previous links

figure 12

Reserve Particular Channels for Connection





Reservation Request Packet (RRP)

- M_D randomly selects as many channels as indicated in the BW field of the CSP ID
- M_D Encapsulates Reservation Request Packet and transmits to first switch on reverse route
  - switch reserves channels for this connection
- Connections at each switch reserved
  - First Switch transmits to second etc.
- M_S receives RRP packet and sends acknowledgement packet to M_D
- M_D sends final acknowledgement packet to M_S
- Transmission begins

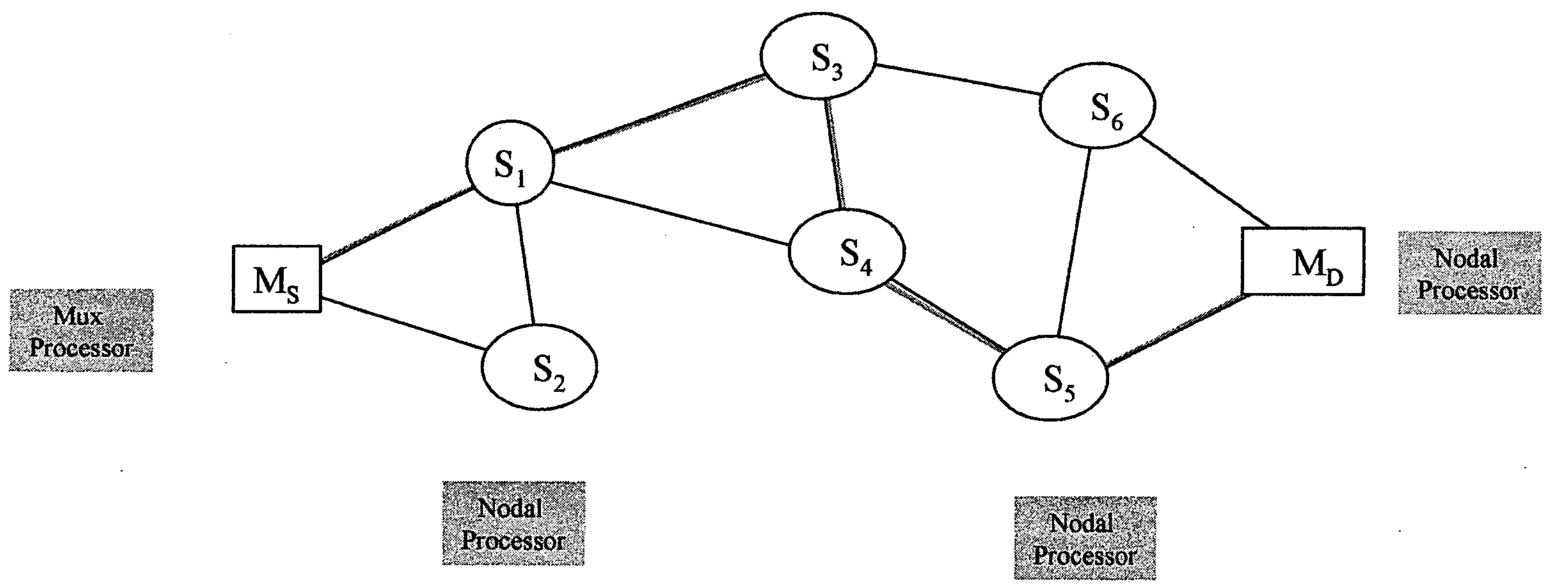
figure 13

What if Reserved Channels not Available?

- Reservation Request Packet (RPP) arrives at a node
  - Nodal Processor finds that channels requested have been taken
    - a 'colliding' RPP got there first
  - Nodal Processor updates 'Line of Sight' State and returns RPP to M_D
  - M_D randomly selects new channels and launches new RPP
- Channels are reserved if possible
  - If not, new channels selected again by M_D and new RPP launched
- Eventually
  - RPP finally arrives at M_S
    - Channels reserved along route
    - Connection can begin
  - Or, route is blocked

figure 14

If Route is Blocked



- M_S eliminates most offensive link from its topology
  - Uses 'Blocking Link' field of CSP Identifier
- Recalculates the Dijkstra
- Re-initiates the process with the next best route

figure 15